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METHOD AND APPARATUS FOR MONITORING AN ANALOG METER

FIELD OF THE INVENTION

The invention refers to a method for monitoring an analog meter by recording a digitized image of the meter whereby the meter comprises a set of graduation segments and at least one needle. The invention further refers to an apparatus for performing the above method.

BACKGROUND OF THE INVENTION

Analog meters have been used in conjunction with sensors to provide visual display of the physical parameter that the sensor is designed to measure. Even though digital meters are now available, analog meters are still used widely, especially for situations where use of electricity is to be avoided for the reason of preventing electrical spark near the fuel storage tanks. These meters are usually installed in widely separated geographical regions so gathering the meter information requires wide-area communication network. Fortunately, the cost of sending compact digital data such as the meter reading or meter conditions is becoming very inexpensive nowadays. One example is the use of Short Message Service of the wireless GSM network. Therefore it is desirable to equip an analog meter installed in the field with a "non-contact" device that is capable of reading the meter digitally and sending the data or other conditions to a user or a computer system on the wired or wireless communication network. The reading device must be flexible to read different meters and must be able to perform a precise reading at reasonable time.

Previous image processing work by Robert Sablatnig et al.: "Automatic Reading of Analog Display Instruments", Proc. of the 12th International Conference on Pattern Recognition

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(1994), pp 794-797 as well as "Machine Vision for Automatic
Calibration of Analog Display Instruments", SPIE Proc. on
Machine Vision applications in Industrial Inspection III,
vol. 2423 (1995), pp 356-366 described methods to read the
5   analog utility (gas, water or electricity) meters. Utility
meters differ from the gauge-like meter. First, a utility
meter has multiple dials. Each dial has a needle that reads
one digit (0-9) of the entire reading. In contrast, the
gauge-like meter has only one dial or scale with fine reading
10   resolution ranging from 1 out of 50 or 1 out of 1000. Second,
the needle of a utility dial rotates continuously in one
direction only. The needle of the gauge-like meter can only
rotate in less than 360 degree and in both directions.
Sablatnig et al. use the Hough transform technique to detect
15   and locate the outlining circles of all dials in the utility
meter. There is no detection of the graduation marks of the
dial. The basic operation of the Hough Transform is described
in Ballard and Brown: "Generalizing the Hough transform to
detect arbitrary shapes", Pattern Recognition Vol. 13(2)
20   (1981), pp 111-122 and E.R. Davies: "Machine Vision: Theory,
Algorithms, Practicalities", Academic Press (1996).

US patent 5,013,154 describes a "System for remotely reading
an analog meter". The teaching of this patent uses a video
25   camera and an information processing system with look-up
table to read gauge-like analog meters. The patent assumes
that a pre-defined path of interest on the image plane is
known. The information processing system extracts the
intensity profile along the pre-defined path from the image
30   and detects the location of the needle pointer based on the
reflectivity difference between the needle and the
background. A relative distance along the defined path
between the needle and the starting point of the defined path
indicates the reading. One assumption that the patent makes
35   is that there is no black character, graphics or scale mark
along the path of interest that can interfere with the black
needle. The patent also assumes that the position and

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orientation of the meter is fixed with respect to the imaging
system.

US Patent 5,673,331 teaches methods for reading gauge-like
analog meters from video images. It also assumes that the
position and orientation of the meter is fixed. Using a pre-
operation calibration procedure to determine data such as the
position of the needle pivot point and the leftmost and
rightmost points of travel of the needle, the system performs
the reading by locating the angular position of the needle
pointer and compares it with the calibrated data. It uses a
2D template matching technique to determine the angular
position of the needle.

US Patent 5,559,894 describes methods for inspection and
reading of utility meters (not gauge-like meters). It first
uses pre-defined templates to identify a particular meters
and determine its relative position and orientation with
respect to the fixture. From the position and orientation
data, the angular positions of all the dial needles are
determined. Again, one dial decides one digit of the meter
reading.

It is an objective of the invention to provide a method for
monitoring an analog meter which is flexible and allows easy
installation for various existing analog meters.

It is another objective of the invention to provide an appa-
ratus to perform that method so that flexible installation
and remote monitoring of various analog meters is allowed.

SUMMARY OF THE INVENTION

With respect to the method the objective of the invention is
solved by a method for monitoring an analog meter having a
set of graduation segments and at least one needle, the
method comprising the steps of: recording a digitized image

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of the meter, the meter; extracting a set of edge points rep-
resentative of the graduation segments from said image; per-
forming a Hough Transform on said set of edge points to ob-
tain a center point of said set of graduation segments; and
5   extracting an intensity profile of said image along a path
through said graduation segments to obtain a set of detected
graduation segments and to obtain a position of said needle
relative to said set of detected graduation segments.

10 With respect to the apparatus the objective of the invention
is solved by an apparatus for performing the above method for
monitoring of an analog meter comprising: a sensor for ob-
taining a digitized image; a processor for extracting a set
of edge points representative of graduation segments of said
15 meter from said image, for performing a Hough Transform on
said set of edge points to obtain a center point, for ex-
tracting an intensity profile of said image along a path
through said graduation segments to obtain a set of detected
graduation segments and for obtaining a position of said nee-
20 dle relative to said set of detected graduation marks; and an
interface device to communicate with a communication network.

The algorithm according to the method locates the center of
the meter scale and then detects the graduation marks of the
25 scale. It detects the leftmost and rightmost travel of the
scale and the needle pointer. From these data, the meter
reading is derived by comparing the relative position of the
needle within the arrangement of the detected graduation
marks. The invention is applicable to utility meter having a
30 graduation scale and at least one needle. The algorithm can
read multiple meters within one image and computes the read-
ing even when the analog meter is viewed from an oblique an-
gle. Due to the parallel shift between the scale and the nee-
dle pointer, additional computational effort must be per-
35 formed. The method employs the Hough Transform to obtain the
center of the scale and the needle. Whereas the Hough Trans-
form usually is used with a continuous area, the method ac-

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cording to the invention applies strong edge points from the
set of individual spaced graduation marks as input signals to
the Hough Transform.

5   Only during the training period, when the method and the ap-
paratus are adopted to a specific meter, it is necessary to
perform the Hough Transform for the detection of the gradua-
tion marks. When the relative arrangement between the meter
and the camera of the sensoring apparatus does not change, it
10   is sufficient to extract the intensity profile and detect the
position of the needle within the graduation scale. When the
algorithm detects that the meter moved, meter and graduation
scale detection by employing the Hough Transform has to be
performed again. As detection criterion for a move of the me-
15   ter, a parameter which represents the accuracy of the loca-
tion of the needle is used. Advantagously, this parameter is
the number of contiguous angles where the intensity profile
is low in the area between the center point and the gradua-
tion marks of the scale. This parameter indicates the width
20   of the needle.

The Hough Transform is performed on strong edge points of the
rectangular shaped graduation marks. The transform computes
candidate segments in the direction orthogonal to the gradi-
25   ent of an edge point and at a predefined distance apart form
the edge point. By calculating an extreme value of the dis-
tribution of the candidate segments and the centroid of the
extreme value, the coordinates of the center of the scale and
the needle are obtained.
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From the intensity profile of the graduation marks each
graduation mark can be individualized by locating extreme
values ("teeth") and applying a deep-pocket criterion to
eliminate any local extreme values which do not originate
35   from a graduation mark.

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When a meter is viewed from an oblique angle the circular
graduation scale appears as an ellipse. A circular intensity
profile may not capture all graduation marks so that more
than one intensity profile at different radii is extracted,
5   and the detected intensity teeth are merged to obtain a full
graduation scale. The correct scale of graduation marks is
detected when the number of teeth is close to the specified
number of graduation marks. Practically, an arrangement of
detected teeth is considered as the correct graduation scale
10 whose number of detected teeth is within plus or minus one of
the specified number of graduation marks.

Further when viewing with an oblique angle, the pivot center
of the needle and the center of the scale do not coincide.
15 Then, another Hough Transform calculates the center of the
needle since the needle either has the shape of a disc or has
a hole near the needle pivot center. The input area to the
Hough Transform can be restricted to the surrounding area of
the scale center. The Hough Transform is performed in the
20 conventional manner.

The method and the apparatus can be used for condition re-
porting of analog, utility type meters using a wired or wire-
less communication network. When the actually captured meter
25 value meets a certain condition, which can be input via the
network, a message or condition report is transmitted to a
central control station. There, further activities can be
initiated.

30 The apparatus for performing the method has a fully digital
architecture and can be further integrated when circuit tech-
nology advances. The imaging subsystem captures the image of
the meter. The embedded processor performs image processing
as well as image analysis to derive the meter reading iin
35 form of a digital value. The CPU may run web server software
so that it reacts to the requests of a client connected
through communication modules within the apparatus, such as

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ISDN, Modem or GSM modules. If the Short Message Service of a GSM network is used, then any cellular phone can read any meter independed of the time and place.

5   BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings show the principles of the invention and an preferred embodiment. Corresponding elements are denoted by like numerals. The drawings show:

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Figure 1   a block diagramm of a meter reading apparatus;

Figure 2   a flowchart of the operation of the apparatus for
           orthogonally viewing the meter scale;

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Figure 3   edge points for a Hough Transform of a contiguous
           area;

Figure 4A and 4B stand 4C candidate segments for a radial
20   line segment of the graduation scale, edge points
           of the graduation scale, and two different sets of
           candidate segments for the full graduation scale,
           respectively;

25   Figure 5A and 5B and 5C different intensity profiles with lo-
           cal maxima and minima;

Figure 6   a relation between a needle pointer and radial line
           segments as well as corresponding intensity pro-
30   files;

Figure 7   a flowchart for the operation of the apparatus for
           oblique viewing the meter scale; and

35   Figure 8   a flowchart for the operation of the apparatus with
           a detection for any moving of the meter.

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DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to an apparatus consisting of
an imaging subsystem and a computer or an embedded processor
to process the image from the imaging subsystem. The image
from the imaging subsystem is digitized and stored in the
computer for further processing. Without loss of generosity,
it is assumed that the image is digitized with a square
spacing.

Usually the camera views the analog meter in an orthogonal or
normal direction. The circular scale will then look like a
circle on the image. However, in some situation the camera
has to be positioned sidewise so that the meter is viewed
obliquely. In this case the circular scale will appear as an
elliptic shape. This invention can deal with both situations.

The method and the apparatus according to the invention
serves to read a wide variety of analog meters. Therefore the
design of the machine vision algorithm is to detect and lo-
cate features that are common among analog meters. From the
image processing perspective, an analog meter consists of a
circular graduated scale, a needle pointer, characters and
logos on the dial surface and a metal or plastic casing. The
graduation scale, the characters and graphic logos are all
located on the scale surface. The needle moves on a plane
that is usually higher than the plane of the scale. Therefore
if the meter is viewed obliquely, the center of the pointer
will not coincide with the center of the graduation scale.

There are many designs of the graduation scale. However,
almost all analog meters have a basic graduation scale that
is represented by short radial line segments (RLS) arranged
in a circle. The angular span of the scale can be from 60
degree (e.g., a voltmeter) to 270 degree (e.g., most pressure
gauges). All radial line segments intercept at the center of
the scale, which is also the center of rotation of the needle

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if the meter is viewed normally. Some meters have duel
graduation marks in reading in different units. The angular
spacing between the scale graduation marks is not necessary
uniform. Because all meters have this radial line pattern,
5   the present invention detects and locates this radial line
segment pattern. By comparing the needle angle with respect
to the angles of the detected graduation marks, the present
invention can read meters with linear or non-linear
graduation scale.

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Many analog meters have longer coarse graduation marks
separated at multiples of the finest graduation marks. In the
present invention, only the finest graduation marks, or the
finest spaced RLS, are detected and used.

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Needle pointers can also take many shapes. In general, a
needle is narrow on one side of the needle pivot point. On
the other side, the shape can be arbitrary, but usually is
wider and shorter. The needle tip may or may not reach into
20   the region of the graduation marks. The needle usually has a
circular shape near the needle pivot center.

Characters and graphics on the scale surface show the coarse
scale numbers, the company logos and other information. Even
25   though useful to a human reader, these characters and graphic
symbols are not detected and used in the present invention.
During training of a meter type, the system needs to know
what reading the leftmost graduation mark is and how much
reading increment for each increment of graduation mark. In
30   some analog meters, the leftmost graduation mark does not
necessarily correspond to a zero reading.

The casing of the analog meter is usually round. If the
casing is made of stainless steel, its reflective surface
35   made it an unreliable feature for image processing. When the
illumination is not diffuse and uniform, the casing can cast
a shadow on the surface of the scale. If viewed normally, the

shadow takes the shape of a partial circle and it co-exists
with other circle features from the round casing.

The automatic reading device 70 shown in figure 1 comprises
5   an image sensor 71 which captures an image of a single or
several analog meters 81, 82. The sensor may be a CMOS image
sensor or a CCD device. The apparatus comprises an embedded
processor 72 which preferably runs with a standard operating
system. The processors 72 performs the algorithm for image
10   analysis and meter reading. The processor has an image proc-
essing subsystem 73 and a communication subsystem, preferably
a web server module 74 as shown in the example. The processor
is connected to one or multiple communication modules, e.g. a
GSM module 75, an ISDN interface 76, or an analog modem 77.
15   The communication module provides connectivity to a wired or
wireless communication network 83. Via the communication net-
work 83 the device 70 can communicate with a central station
which monitors the operation of the device or responds to in-
puts from the device. Any communication over the wireless
20   communication network may employ Short Message Service. The
device 70 may also receive control inputs from a cellular
phone 84. The input may be a reference value for comparison
with the meter reading. When the read value exceeds the ref-
erence value, a transmission of a message is performed.
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Figure 2 shows a flow chart depicting an overview of the
vision algorithm software performing the automatic reading of
an analog meter when the meter is viewed from a normal
direction. For an oblique-view image of a meter, more
30   processing steps are needed which will be described later in
connection with figure 7. In the first step 8 of Figure 2,
two 3X3 Sobel edge operators are convolved with the image of
the analog meter to obtain the horizontal and vertical edge
gradient (g_x, g_y). The magnitude and the direction of the
35   edge gradient are computed. All pixels with a gradient
magnitude greater than a threshold are classified as strong
edge points. The threshold for the gradient magnitude should

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be set so that most of the edge points of the graduation
marks are selected. It can be a fixed parameter or defined
during the meter type training stage by computing the average
gradient magnitude of the graduation marks in an area
5   selected by the human trainer.

Hough transform (HT) in general is used extensively in the
past for the detection of lines, circles, ellipses, and other
shapes such as corners, and polygons. The book by Davies has
10   an extensive discussion on the techniques. In the prior art,
the shape detected by Hough Transform is mostly formed from
one single contour, whereas the invention uses the Hough
transform for the detection of multiple radial line segments
(RLS) arranged on a circle. The RLS as such are separated
15   from each other. To explain the Hough Transform technique for
the circular RLS pattern, it is instructive to review the HT
for the circle detection first. Referring to Figure 3, the
black disk 16 has an irregular boundary 20. After edge gradi-
ent operation and thresholding, all strong edge points, such
20   as A, B, or C, lie on the boundary 20. For a black disk, the
edge gradient points outward. Thus at strong edge point A,
the opposite of its edge gradient 17 points toward the center
of the circle. Therefore if the radius of the circle R is
known, a candidate center point that is R distance away from
25   the edge point A along the negative gradient direction 18 is
placed on a so-called parameter plane. The parameter plane
refers to the x- and y-coordinates of the center of the cir-
cle. Each candidate point is a vote at its location on the
parameter plane. For another strong edge point B that is also
30   on the edge of the same circle, another candidate center
point will be placed close to the previous one. On the other
hand, for a strong edge point C that is not on the edge of
the same circle but on the irregular boundary 20, its candi-
date center point will be located at some other place. By ac-
35   cumulating all the candidate center votes from all strong
edge points, a cluster 19 will be formed at the center of the
circle. The location of the circle can then be determined by

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peak detection of the cluster. If the radius of the circle is
not known, then the parameter space becomes three-
dimensional, or multiple parameter planes. Each parameter
plane is used to accumulate candidate center points for each
5 circle of specific radius. If a peak is detected on a parame-
ter plane of a particular radius, then a circle with this
specific radius with center at the peak location is found.
Since multiple parameter planes consume large memory, there-
fore in practice a range of potential radius is given and
10 only one single parameter plane is used. In such case instead
of placing a candidate center point, many points along a can-
didate center "line segment", which corresponds to the range
of potential radius, is placed on the parameter plane for
vote accumulation. Then a peak corresponds to the detection
15 of a circle with a radius within the range given. If needed,
further processing can determine the exact radius of the cir-
cle. With a slight modification, the Hough Transform can be
used to detect a hole whose edge gradient points inward to-
ward the center of the circle.

20 The Hough Transform according to the invention for the circu-
lar RLS pattern is now described. Like the circle Hough
Transform, only a single parameter plane will be used for
vote accumulation. Referring to Figure 4B, under spatial dig-
itization, each RLS is a narrow rectangle 28. The previous
25 edge extraction step 8 actually extracts two lines of strong
edge points such as 29, 30 along two sides of the medial axis
34 of the RLS. The two edge points 29, 30 of a RLS have oppo-
site gradient direction 32, 33 and are slightly off from the
medial axis of the RLS. Ideally, the center of the RLS pat-
30 tern lies on the medial line of the RLS, not the two edges of
the RLS. However, it is assumed for now that the edge points
are very close to the medial line.

35 It is assumed that the mean radius R_0 of the circular RLS
pattern, or the distance from the center of the pattern to
the middle point of the graduation mark, is given. Referring

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to Figure 4A, for each strong edge point 22 (which can come
from either side of a RLS), a candidate line segments 23 or-
thogonal to the edge gradient 25 is placed on the parameter
plane for vote accumulation. The distance from the strong
5   edge point 22 to the middle of the candidate line segment 23
should equal to the mean radius R_0. The length of the candi-
date line segment, which is denoted as G, is selected as a
fixed factor α multiplied by the length L of the RLS, which
is also given. Usually this factor is greater than 1. Since
10   the center of the pattern can be located on either side of
the strong edge point 22, another mirrored candidate line
segment (not shown in Figure 4A) on the opposite side of the
strong edge point 22 will also be placed on the parameter
plane. For another strong edge point 26 on the same RLS,
15   similar candidate line segments 27 of length G, with an axial
shift, will be placed on the parameter plane. The accumulated
votes from all edges points on a RLS form a trapezoidal line
spread function 24. The base of the trapezoidal line spread
function has a width of G + L and the top plateau region has
20   a width of G − L. For edge points on another RLS, two candi-
date line segments with the same line spread function will be
placed on the parameter plane with a slightly different an-
gle. As shown in Figure 4C the one of the candidate line seg-
ments focusing toward each other will create an overlapping
25   radial pattern 35 around the center of the original circular
RLS pattern 21 while the other set 36 will spread widely
around a larger circle. This vote distribution function on
the parameter plane will have a peak 37 located at the center
of the RLS pattern 21. Normally the peak to background ratio
30   is very high for analog meters because most of the non-RLS
related edge points contribute candidate points that are
spread sparsely on the parameter plane. On the other hand,
there are 10 − 15 strong edge points from each of the 50 −
100 graduation marks that contribute candidates line segment
35   concentrating near the center of the RLS pattern.

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The two processing parameters: the mean radius R_0 of the cir-
cular finest graduation marks and the length of the finest
graduation marks L, depend on the meter type. Both parameters
are defined during the training of the meter type. When a me-
ter of multiple graduation scales exist, the selection of
mean radius R_0 decides which graduation scale will be used.

The use of the edge points in lieu of the median line points
for Hough Transform described above can be improved by a sim-
ple technique. Referring back to Figure 4B, if the distance W
between the two edge points 29, 30 is known, then an esti-
mated median line point can be obtained by shifting the edge
point a distance W/2 along the negative edge gradient direc-
tion. Ideally the distance W is determined by the number of
pixels sampled across one graduation mark (or one RLS) which
varies from meters to meters and from fine graduation marks
to coarse graduation marks. Experiments show the shift of 1
pixel is satisfactory for most meters with appropriate image
resolution (320 x 240 to 640 x 480 pixels).

The next step 10, shown in Figure 2, is to detect and locate
the peak from the vote distribution function generated from
the Hough Transform described above. If there is only one
circular RLS pattern (or one analog meter) in the image,
which is usually the case for analog meter reading, then the
peak can be determined by finding the maximum of the vote
distribution function. If there are multiple meters in the
image, then the second peak can be found by searching for a
maximum after zeroing out the value of the vote distribution
function around the first peak region. The process can be re-
peated for detecting more meters. The center of the circular
RLS pattern can be estimated by computing the centroid of the
peak, e.g. using the formula

$$x_c = \sum_{i,j} x_i f(x_i, y_j) / \sum_{i,j} f(x_i, y_j),$$
$$y_c = \sum_{i,j} y_j f(x_i, y_j) / \sum_{i,j} f(x_i, y_j).$$

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The summation is over a limited area around the peak of the
vote accumulation function f. Because the peak to background
ratio is usually high, the centroid estimate is not very sen-
sitive to the size of the summation area as long as the en-
tire peak is included within the summation computation.

The detection and localization of the RLS pattern by the
Hough Transform according to the invention do not require
that the radial line segments occupy a complete circle or are
uniformly distributed in angle. Graduated scales of most
pressure gauges have a 270 - degree span while scales of most
electronic analog multi-meters have less than 90 - degree
span. However, the estimated centroid location of the RLS
pattern is slightly sensitive to the correctness of the mean
radius given, especially if the angular span of the RLS
pattern is less than 180 degrees. This is because if the mean
radius given is either shorter or longer, the line spread
function 24 (Figure 4A) coming from an RLS will not be
centered at the center of the RLS pattern. Thus if there is
no similar line spread function contribution from an RLS 180
degree apart, the accumulated votes will not be symmetrical
around the center. When contiguous candidate line segments
are missing from one side, then the computed centroid will be
shifted away from the true center of the pattern.

The center of the RLS pattern corresponds to the center of
the meter's scale. The next step 11 (Figure 2) is to extract
the intensity profile of the image cutting through the
finest-spaced graduation marks. A circular path centered at
the estimated center of the RLS pattern and with the mean
radius R_0 is used to extract the intensity profile. The next
step 12 is to detect and locate the individual graduation
marks. A graduation mark appears as a deep-pocket minimum,
called a "tooth", on the intensity plot. For repeated black
graduation mark pattern(s), the teeth form a comb-like
pattern on the intensity profile. Since there are characters

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or graphics on the scale surface, the intensity profile may
contain other teeth that have a spatial frequency quite close
to that of the graduation marks. In other words, the
intensity profile can contain sections of comb-like teeth
5   structure from characters and graphics quite similar to those
from the graduation marks. The algorithm needs to distinguish
combs corresponding to the graduation marks from combs that
are not graduation marks.

10   A detailed explanation of the step 12 follows. First all the
teeth are located. Then the spacing between teeth are checked
so that only contiguous teeth with spacing less than a
threshold are grouped into combs. Finally the one comb with
the number of teeth that is close to a specified number of
15   graduation marks is considered as the correct graduation
scale. From this detected graduation scale, the angular
positions of the beginning of the scale and the end of the
scale are determined. Referring to Figure 5A, a tooth is
defined as a local minimum in intensity 38 whose intensity's
20   increase to the nearby local maxima 39, 40 is greater than a
pre-defined threshold, as shown in the figure with the data
points circled. This deep-pocket criterion for both sides of
the local minimum can eliminate an intensity edge as shown in
Figure 5B. However, it also ignores some legitimate teeth as
25   shown in Figure 5C that occurs because of the noise in the
image intensity (left diagram) or a thick graduation mark
(right diagram). Therefore the software will detect these
teeth by finding two neighboring one-sided steep minima 41,
42 that are separated by a distance less than a threshold. In
30   this case, the location of the teeth is defined as the
midpoint between the two local minima. Once all the teeth are
detected, the algorithm then checks for the spacing between
neighboring teeth. All teeth with neighboring spacing less
than a threshold are grouped into one comb. This spacing
35   threshold can be computed as the median value of all the
spacing between neighboring teeth. In other words, there are
50% of the neighboring teeth's spacing below this threshold

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and 50% above. The median of the teeth's spacing, instead of
the average of the teeth's spacing, is a reliable method to
estimate the spacing between the graduation marks because
more than 50% of the teeth detected are graduation marks.

5   Since the intensity profile is an angular function, the
beginning and the end of the profile array actually are
neighbors. Thus the algorithm needs to check if a comb at the
end of the intensity profile actually connects to a comb at
the beginning. After all the combs are detected, the
10   algorithm finds one comb whose number of detected teeth is
within plus or minus one of the designed number of graduation
marks. This comb corresponds to the graduation scale. The
reason for plus or minus one is to account for the tip of the
needle pointer. As shown in Figure 6, when the tip of the
15   needle is included in the intensity profile, its position can
either overlap, separate slightly or separate completely from
the graduation marks as shown in the left, middle and right
diagrams. The corresponding intensity profiles of these three
situations are shown at the bottom. For the right diagram
20   case, the total number of detected marks is one extra. For
the middle case, the needle and the touching graduation mark
may both be missed because of the intensity fluctuation.
Therefore the detected number is one less. For the left
diagram case, the detected number of graduation marks is the
25   same as the designed number.

When none of the comb has a teeth number that matches the
designed number of graduation marks, then it is possible that
some graduation mark has so low a contrast that it is not
30   detected. In this case, the graduation scale is divided into
two or three combs. Therefore the algorithm checks for two or
three neighboring combs to see if the total number of teeth
come close to the designed number of graduation marks. If
yes, then the algorithm can interpolate the missing
35   graduation marks. If no, an error message is given.

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Next step 13 is the detection and localization of the needle
pointer. When the meter is viewed normally, the scale center
coincides with the needle pivot point. Since the needle can
rotate to any angular position within the range of the scale,
the black needle can overlap with the high-contrast black
graphic background at many possible needle angles. Therefore
two sides of the needle may not appear as straight lines. To
avoid the problem due to complex background, patent 5,673,331
uses the template matching technique to match the shape of
the needle at various angles to the image. The angle with the
best match score determines the angle of the needle. The
technique requires that the shape of the needle be trained
first. The present invention, however, uses a simple and fast
method that also overcomes the problem of cluttered
background. This technique is based on the observation that
at angles where the needle is located, the radial intensity
profile from an inner radius $R_1 = a * R_0$ to an outer radius
$R2 = b * R_0$ shows "contiguously" low value. There the
algorithm searches for those angles whose intensity values of
the radial intensity profile are below a preset threshold
"contiguously" between radii R_1 and R_2. Typical values for a
and b are 0.4 and 0.85 respectively. Both parameters can be
meter-dependent. Since a needle has some finite width,
several contiguous angles satisfy this requirement. Then an
average can be taken as the needle angle if all angles are
contiguous. If there are more than one group of contiguous
angles, then it is an indication of multiple detected
needles. For analog meter with only one needle, multiple
detected needles will signal an error.

Once the angle of the needle is extracted, the next step 14
is to project its angular position onto the graduation marks
detected earlier. If the number of graduation marks is one
more than the designed number, it can be verified now that
the extra tooth indeed comes from the needle. If not, it is
possible that the pointer does not appear as a separate teeth
and some spurious intensity noise has generated the extra

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teeth. By examining the spacing between the teeth, this spu-
rious tooth can be removed.

The last step 15 is to convert the needle angle to meter
reading. There are two methods. The first is to find the two
graduation marks where the pointer lies between. From the
relative angular position of the pointer and the two
neighboring marks, a sub-graduation reading can be made by
interpolating between the angles of the two graduation marks.
The second method is to fit all the detected graduation marks
with a continuos linear function or nonlinear function so
that a mapping between the angle to the reading can be made.
Knowing the angle from the first scale mark to the needle,
the reading can be obtained from the fitted mapping function.
As mentioned in the beginning, the first graduation mark may
not necessarily represent a zero reading.

The processing flow as shown in Figure 2 can determine the
arbitrary position and orientation of the analog meter. This
is especially useful during the training phase, or during the
field installation testing after installing the automatic
reader to the field meters. Afterward, if the imaging
conditions remain the same, then the position of the scale
center, the angular position of the first graduation mark,
the average spacing between graduation marks and the mapping
between angle to reading will not change. Therefore for a new
reading, only the needle angle needs to be detected and
located. In other words, only the last three processing steps
13, 14, 15 in Figure 2 are needed once the relative positions
between the meter and the meter reader is fixed.

Refering to Figure 8, the switching between the full
processing of meter reading (8 - 12 in Figure 2 and step 93
in Figure 8) and needle localization processing (13 - 15 in
Figure 2 and step 93 in Figure 8) can be done automatically
by using one parameter readily available in the needle
localization processing. In the processing step 13, There are

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several contiguous angles where the intensity is contiguously
below the threshold intensity along the radial direction from
R_1 to R_2. When there is one needle detected, the number of
these contiguous angles (denoted as N) is proportional to the
width of the needle and should remain roughly the same when
the needle is rotated to different angle. However, if the
relative imaging conditions changes (such as the when the
analog meter is moved), then the needle localization
processing can detect no needle, or multiple "false" needles,
or possibly one "false" needle. Therefore, when one needle is
detected, the algorithm checks if N changes substantially
from the previous needle localization processing in step 94.
If yes, it is an indication of the change of imaging
conditions and the algorithm switches to the full processing.
This process is shown in Figure 8 when the algorithm performs
the meter reading continuously in a loop 93, 94, 95, and 96.
Since the meter and graduation scale detection/localization
normally take longer to compute, the partial processing of
needle localization can increase the response time of the
system substantially. Thus, the processing time which is in
the range of several seconds for the full algorithm including
Hough Transform can be reduced to a fraction of a second for
the needle detection and localization only.

The algorithm described above can be extended for situations
when the camera views the analog meter from an oblique angle.
There are several changes to the image. First, the circular
graduation scale becomes an elliptical graduation scale.
However the radial line segments of the graduation marks
still intercepts at the center of the graduation scale.
Therefore the Hough Transform according to the invention
still works for the elliptical radial line segment pattern.
If the oblique viewing angle is Φ, then along the major axis
of the elliptical graduation scale, the mean major radius is
still R_0 and the mean minor radius is reduced to $R_0 * \cos\Phi$
along the minor axis. The length of the radial line segment
is also reduced by a $\cos\Phi$ factor from the major axis

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direction to the minor axis direction. The spacing between
two contiguous graduation marks however is reverse, going
from a distance of Δg to $\Delta g * \cos\Phi$ from the minor axis to
the major axis. In other words, the ratio of the angle of two
5   contiguous graduation marks along the major axis to that
along the minor axis is $\cos^2\Phi$. The second change in the
oblique meter image is that the center of the pointer no
longer coincides with the center of the graduation scale.
This is because the pointer rotates on a plane that is higher
10   than the plane of the scale. Therefore the technique to
perform the reading from an oblique image will be different.
The third possible change is that the round casing of the
analog meter may obstruct some graduation marks. The present
invention can still perform the reading of an analog meter
15   even when part of the radial line segment is missing for some
graduation marks. If the obstruction is so large that the
complete radial line segment is missing for some graduation
marks, then the system will raise an error message.

20   Figure 7 depicts an overview of the processing flow when the
meter is viewed obliquely. The first step 52 is the same as
that in Figure 2. The second step 53 uses the Hough Transform
algorithm according to the invention to detect and locate the
elliptical RLS pattern. It is similar to that for the
25   circular RLS pattern except that the two operating parameters
R_0 and L need to be selected differently. From the center of
the graduation scale, the strong edge points of the
graduation marks can now have a shortest distance of $R_0 *$
$\cos\Phi - L * \cos\Phi/2$ up to a longest distance of $R_0 + L/2$.
30   Therefore instead of specifying R_0 and L to the Hough
Transform algorithm, the user selects the shortest distance
R_1 and the longest distance R_2 of the edge points of the
graduation marks during the training. The system computes the
R_0 and L by using the formula: $R_0 = (R_1 + R_2)/2$ and $L = R_2 - R_1$.
35   The length of the candidate line segment G on the parameter
plane is then equal to $\alpha * L$, where α can be a fixed number
different from that for the circular RLS pattern.

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The following step 54 is also the same as that in Figure 2.
The peak from the vote accumulation of the Hough Transform
still stands out clearly on the parameter plane. The next two
steps 55, 56 are the same as those in the case of circular
RLS. There are two situations. When the viewing angle is
small or the graduation marks are long, the intensity profile
can capture all the graduation marks and the graduation scale
can be detected correctly. Then the algorithm can proceed to
step 58 after the decision box 57. However, if the viewing
angle is large, the intensity profile along one single circle
may not capture all the graduation marks that are now on an
ellipse. In this case only certain sections of the graduation
marks will be detected on one single intensity profile.
Multiple circular intensity profiles at different radii are
needed. This is done in step 62 by repeating the extraction
of intensity profiles and the detection of the graduation
marks from all circles with radii ranging from R_1 to R_2. The
teeth extracted from on intensity profile can correspond to
some points one the graduation marks of the meter scale, but
not all. Furthermore multiple teeth extracted from intensity
profiles of different radii can belong to the same graduation
mark. Thus step 63 is used to merge all the angular
coordinates of all the teeth together, then order them
according to the angular value, and then group teeth with
nearly the same angular positions together. Each grouping of
the teeth can correspond to one graduation mark, or a
corresponding angle of a radial line segment. The angular
position of the graduation mark can then be computed as the
average or the median of all the teeth in one grouping. At
this point, there is one comb whose number of teeth is within
plus or minus one of the design number of graduation marks.
Then this is the detected graduation scale with each
graduation mark located at an angular position that is the
average of all angles belonging to the same radial line
segment as mentioned earlier.

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After the graduation scale is detected and located in 57 or
63, the next step 58 is to detect and locate the center of
the needle. As mentioned earlier, the center of the needle
does not coincide with the center of graduation scale
obtained in 54. To determine the center of the needle, the
traditional Hough Transform for circle detection is used
since the needle has the shape of either a black disk or a
white hole near the needle pivot center. Due to the fact that
the center of the needle is not far from the center of the
graduation scale, the Hough Transform can be speeded up by
using only strong edge points within a region near the
graduation scale center. Once the center of the needle is
obtained, the needle angle can be determined using the same
technique 13 of Figure 2. However this needle angle is with
respect to the needle center, not the center of the
graduation scale where the reading can be made. Therefore, a
vector originating from the center of the graduation scale
and parallel to the needle angle can be drawn. This vector
corresponds to the projection of the needle pointer from the
needle rotational plane to the plane of the graduation scale.
Once the pointer is on the scale plane, the angular position
of the pointer from the first graduation mark can be
determined and the reading can be obtained using the same
algorithm as described in step 15 of Figure 2.